1942

Pin-connected plates, BSCE Thesis, Lehigh University, 1942

H. G. Luley

~~176A~~
1885

FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA

PIN-CONNECTED PLATES

by

Howard G. Luley

Lehigh University

1 9 4 2

This Thesis is presented to the Faculty of the Civil Engineering Department in partial fulfillment of the requirements for a Bachelor of Science in Civil Engineering degree.

Date

This Thesis is accepted by the Faculty of the Civil Engineering Department in partial fulfillment of the requirements for a Bachelor of Science in Civil Engineering degree.

Head of Department
Director of Fritz
Engineering Laboratory

Date

Associate Director of
Fritz Engineering Laboratory

TABLE OF CONTENTS

PIN CONNECTED PLATES

SYNOPSIS

The results of sixteen tests on pin-connected plates made of four different structural alloys are presented herein. The specimens were loaded in tension by means of a two-inch steel pin which passed through a hole in one end of the plate. A comparison of the relative strength of the different metals and a comparison of the ratios of the ultimate strength of the plate to the ultimate strength as predicted by an empirical formula based on tensile coupon results are given special attention. A study of initial yielding as shown by mill scale peeling and by using curves of Huggenberger tensometers data is also made.

INTRODUCTION

The Committee of the Structural Division on Design of Structural Members of the American Society of Civil Engineers was organized in January 1940, with the purpose, "To consider the physical properties of metals and their influence on the design of structural members for resistance to static, dynamic, and pulsating loads". In line with this purpose the committee has undertaken a study of the physical properties of four structural alloys in relation to their behavior under varying conditions of stress and shape.

This study is made up of tests on Tension and Compression specimens of many different varieties, Torsion and Shear tests, Bending tests, Connection tests, and Special tests. The portion of the project dealt with herein is that of the Connection tests of pin connected plates.

In an actual structure the principal stresses no longer act in only one direction, as in a tension test, but may exist in any direction, in any combination, and may vary more or less rapidly in direction and magnitude from point to point, depending on shape and load characteristics.*

The results of the work with pin-connected plates will give a comparison of four different structural metals as to their relative strengths, and will also give a comparison of the results of ultimate strength and yield strength of the pin-connected plates with the corresponding strength determined by tensile coupon tests. The latter comparison shows how the pin plate design computations relate to the tensile values of the metal.

There have been numerous investigations of pin-connected plates previous to this work, but they relate mostly to the design features of the connection, and comparisons of multi-riveted and pin-connected joints. One of these

- -

* Preliminary Progress Report, Committee of the Structural Division on Design of Structural Members, A.S.C.E.

previous investigations is a paper by Bruce Johnston on Pin-Connected Plate Links* in which he studied the effects of plate thickness, side and bottom edge distances, and pin clearance in relation to the general yield and the ultimate strength of the link. This work considered the design of the plate in relation to its strength. Also the "dishing" phenomenon, which greatly reduces the ultimate strength of thin plates unsupported laterally, was given special attention.

The Quebec Bridge paper° is the result of the tests conducted at McGill University on model links and on full sized hangers with twelve-inch pins with regard to the construction of the Quebec Bridge. The results of these tests are compared with those of Johnston's in his paper "Pin-Connected Plate Links". In the Quebec Bridge paper the "dishing" phenomenon was also taken into consideration.

In this work the "dishing" will not be taken into consideration because the proportions used in the test specimens were such as to avoid this phenomenon.

Another paper which compares the different structural metals in the form of connected joints is that of

- -

104

* Paper No. 2023, A.S.C.E. Transactions, Vol. 4 (1939) page 314.

° Vol. 1, pages 222-227, Report of Canadian Government Board of Engineers, 1919.

"Comparative Tests Of Riveted And Pin-Connected Joints Of Steel And Aluminum Alloys*. The objectives of this work were to determine the load-slip characteristics, the load distribution, and the ultimate strengths of a number of different types of riveted and pin-connected joints.

TEST PROGRAM

A program of sixteen tests was laid out to cover a comparison of four different structural metals. Two different sizes of plate were used in this program as are shown in Fig. 2 and 3. The one series, plates of 4-in. width, were designed to fail in tension, i.e., at the sides of the pin hole. The other series had a plate width of 5 in., and were designed to fail in bearing, i.e., behind the pin hole. The plate thickness of 1/2-in. and the hole diameter of 2 in. are constant for all tests. The length of the steel specimens was 23 in., while the length of the aluminum alloy specimens was 24 in., but this difference in length has no bearing upon the results of the tests.

The material for these tests was of four different structural metals, namely: Carbon Steel, Low-Alloy Steel, Silicon Steel, and Aluminum Alloy (27S-T). All plates were cut with a band saw. The steel plates were machined to shape while the aluminum alloy plates were sawed directly to shape.

- -

* By L. S. Moisseiff, E. C. Hartmann, and R. L. Moore
Presented at the Annual Meeting of the A.S.C.E., January 1942

Tensile coupon specimens were cut longitudinally from the same stock. These coupon specimens were used to obtain the tensile properties of the different metals. The aluminum alloy was donated for these tests by the Aluminum Company of America, and the steel material was purchased from the Bethlehem Steel Company.

The width of the plates was measured to the nearest hundredth of an inch with a steel scale, and the other dimensions around the pin hole were measured to the nearest thousandths of an inch by micrometers.

APPARATUS AND TEST PROCEDURE

The arrangement of the apparatus used during the typical test is shown by the diagram of Fig. 1, and by the photographs of Fig. 5, 6, 7, 8, and 9. The pin holder consisted of two steel blocks, as shown in the diagram, to hold the pin in a cradle-like seat to prevent movement. These pin holders were placed on the upper stationary head of the machine on both sides of the opening which ordinarily is the grip housing for tensile tests. The blocks were designed for a very low shear stress, which governed over bending moment, and a deflection of one-thousandth of an inch.

The pin was a two-inch cylinder of 30 carbon hot rolled mill steel that fitted through the hole in the specimen and seated in the cradle of the blocks. Two holes were tapped into the pin on both sides of the specimen so as to hold a Y-shaped bar. A lock nut on the bolt was tightened so that the Y-bars were rigidly fastened to the pin. These bars were about one inch wide and were cut down at the lower end to one-half inch, so that the Ames dials attached to this end would be centered. The Ames dials were attached by means of small bolts and nuts thru holes in the side of the Y-bar.

Another bar on which the Ames dial stems rested, was rigidly clamped onto the specimen so that it would move downward with the specimen to measure the deformation of the pin hole on the dials. The Y-bars were clamped in position at the bottom with two small steel straps, held together by clamps, so that the Ames dials would remain stationary.

The following observations were made at successive loads during each test:

(1) Longitudinal deformation between the pin and the plate was measured by two 1/1000 Ames dials attached rigidly as described above. These dials were read to 1/10,000-inch by estimating the last figure. This was

necessary because of the small deformation in most readings. The graph was plotted of the longitudinal deformation as abscissas and the load as ordinates.

(2) In the case of two different size specimens, of carbon steel, and of aluminum alloy, strains in the pin plate material were measured at three positions near the top of the plate by means of Huggenberger tensometers. The Huggenbergers were arranged as shown in the photographs of Fig. 8 and 9, and the diagram of Fig. 4. There were three sets of two Huggenbergers each; one set placed on both sides of the pin hole, and one set behind the pin. The Huggenberger tensometers were used to indicate initial yielding of the material around the pin hole.

(3) The surface slip lines which are visible in the mill scale of structural steel, due to yielding of the metal, were brought out by coating the surface of the metal around the pin hole with whitewash. The formation of slip lines at different loads was recorded on at least one of each type of specimen with the exception of the aluminum alloy specimens. One of the aluminum alloy specimens was whitewashed and tested to see if slip lines would form. None appeared until near failure, and the lines that did appear were caused by the small stress lines which only appear near failure due to over-strain in the material. This

agrees with a statement made by Mr. R. L. Moore*, in a letter of October 30, 1942. "In answer to your question, (Can slip lines be observed on aluminum alloy?) there is nothing to use on aluminum alloys to indicate slip lines since such phenomena do not generally occur. The use of whitewash on specimens of mild steel is apparently an old practice with steel investigators, but just what the real value of this procedure is, other than to show a pretty picture, I have never been able to determine. I would be very much surprised if your load-deformation measurements did not indicate yielding in the plate long before any such behavior could be detected from slip lines."

A similar routine was followed in all of the tests. Load was applied in constant increments of 2000 lb., except with a few of the first tests in which 1000-lb. increments were used. The latter increments were increased to 2000 lb. when it was seen that 1000-lb. increments were not needed. Permanent set was taken at 30,000 and 40,000 lb. in the case of Silicon Steel and Low-Alloy Steel. In the case of Carbon Steel the permanent set was taken at 10,000, 20,000, and 30,000 on the four-inch width specimens, and at 20,000

- -

* Research Engineer, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pennsylvania

and 30,000 on one five-inch width specimen. No readings of permanent set were taken on the other five-inch width Carbon specimen. In the case of aluminum alloy permanent set readings were taken at 10,000, 20,000, 30,000, and 40,000 lb. On the curves of load-deformation only the permanent set readings that show definite deformation were plotted.

TEST RESULTS

Tensile Coupon Tests:- Tests for tensile properties of the metals were made by the Fritz Engineering Laboratory Staff, and a summary of the results of these tests are shown on Table 2. The tabulated values of Table 2 are denoted as follows:

σ_p is the proportional limit, which in this case is the point at which the stress-strain curve deviates from the initial elastic portion of the curve by an amount equivalent to the smallest measurable strain.

σ_{UY} denotes the upper yield point, which is the maximum stress in that part of the curve after the elastic portion where a sudden increase in strain is accompanied by a pronounced decrease in load.

σ_{LY} denotes the lower yield point, which in this case was taken at a 0.2 per cent set. This value was chosen because it is the defined value of yield strength for Aluminum Alloys, and was used for the steel alloys to give uniformity for comparison of the data. In this work the lower yield point has been denoted as the yield strength on the curves.

σ_{NM} denotes the nominal maximum stress obtained by using the original area.

σ_{TM} denotes the true maximum stress which was obtained by using the actual area at that particular load.

σ_{TB} denotes the true failure stress obtained by using the actual area at failure.

Measures of ductility were made by determining the Ductility Indices*. The "true" ductility indices are obtained simply by determining the least area of the tensile specimen initially (A_o), at the maximum load (A_u), and after fracture (A_b). The true indices of ductility are then defined as: Uniform ductility index ($\mathcal{E}_u$) = true strain between zero and maximum load = $\log \frac{A_o}{A_u}$. Necking ductility index ($\mathcal{E}_n$) = true strain at most reduced section between maximum and breaking load = $\log \frac{A_u}{A_b}$. Overall ductility index ($\mathcal{E}_b$) = total true strain at most reduced section between zero and breaking load = $\log \frac{A_o}{A_b} = \mathcal{E}_n + \mathcal{E}_u$.

---

* On Compression and Tension Tests of Structural Alloys, Bruce Johnston and Francis Opila, Proceedings of A.S.T.M. Vol. 41, 1942

The modulus of elasticity for the different alloys was not determined because the equipment used for making the tensile tests is not generally used for modulus determinations.

The specimen numbers for the different alloys are denoted as follows: M for low alloy steel, C for carbon steel, S for silicon steel, and Al for aluminum alloys.

The tests for the tensile data were made using the Templin-Type Electric Automatic Extensometer which records a curve of load vs. strain while the specimen is being tested. The curves shown were plotted from data obtained from the curves produced by the automatic extensometer. The specimens used were of the round, threaded end type with an area of approximately one-tenth of a square inch.

TABLE

Alloy	A.S.T.M. Standard Number	A.S.T.M.		Coupon Tests	
		Y.S.	U.S.	Y.S.	U.S.
Low Alloy Steel	A242-41 (tentative)	50,000	70,000	55,500	77,250
Silicon Steel	A94-39	45,000	80,000	53,000	91,050
Carbon Steel	A7-39	33,000	60,000	28,400	46,750
Aluminum Alloy	*	45,000	58,000	48,350	61,900

* Values were obtained from the Structural Aluminum Handbook, Aluminum Company of America, Pittsburgh, Pennsylvania, 1938 Table 37, page 164.

As can be seen from the table shown above, all the alloys with the exception of Carbon Steel are within the minimum values of stress assigned as standards by the American Society for Testing Materials. The carbon steel values are lower than the standards because the metal used for both the tensile coupon tests and the pin-connected plate tests was taken from Soft poor material. At the beginning of the tests this was not known, as it was thought that the metal was of full strength. However, the values determined by the tests in this work will be used, as the results coincide closely. The values for Aluminum alloy taken from the Structural Aluminum Handbook were values presented for 1/2-in. plate of 27 S-T. The values of 27S-T are not the general values for the metal, but are special values for plate which apply more so in this case than the general values.

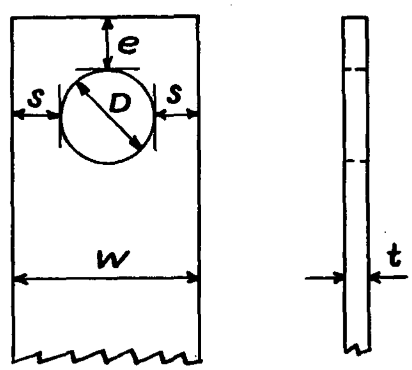

Plate Tests:- A summary of the data obtained by the pin connected plate tests is shown in Table 1. The symbols used as column titles in this table are denoted as on the figure shown. The ratios of columns 8 and 9 are edge distance to diameter of the pin hole (S/D), and the distance behind the pin hole to the diameter of the pin hole (e/D), and are used to find the average bearing stress between the pin and the plate at ultimate strength, S_{bt} (column 13). Load can be interchangeable with stress due to the fact that bearing area is one square inch. This average bearing stress gives an estimate of the ultimate strength according to the design of the plate. The empirical formulas used to find these values are as follows:

Failure by fracture at the side of the pin hole, tension;

$$S_{bt} = 2S_t \left(\frac{S}{D}\right)^* \qquad (1)$$

Failure by fracture behind the pin hole, bearing;

$$S_{bt} = S_t \quad 1.13\left(\frac{e}{D}\right) + \frac{0.92 \quad \left(\frac{S}{D}\right)}{1 + \left(\frac{S}{D}\right)} \quad * \qquad (2)$$

The notations in regard to dimensions of the plate are seen above, and S_t is the ultimate tensile strength of the material as determined by the tensile coupon tests. The limitation as regards the dimensions is: (e/D) between 0.3 and 1.2*. The ultimate strength as obtained by the pin-connected plate tests is in column 15 as load in pounds. These values agree very well with those obtained by the formulas (1) and (2) in column 13, with the exception of silicon steel which has a test value lower than that obtained by the formula.

- -

* Pin-Connected Plate Links, Bruce G. Johnston, A.S.C.E. paper No. 2023.

The observance of the slip lines are shown in columns 11 and 12. These values will be discussed later in connection with the Huggenberger Tensometer data.

The yield strength as load in pounds is given in column 14, and was taken from the curves of Fig. 10, 11, 12, and 13. This yield strength was taken at a set of 0.2 per cent to correspond to tensile test results in which the yield strength is determined by a permanent set of 0.2 per cent. However, on the curves the value of the set is 0.02 in. per inch because there was approximately a 10-in. gage length used on the plate tests. This value is again an arbitrary point which will differ in different investigations. However, with the 0.2 per cent set used in this case the point falls shortly after an initial yielding of the material is shown on the curves by a pronounced increase in strain value as regards to load.

The vertical diameter of the pin hole after the tests as shown in column 16, gives a value of the total deformation of the hole, and the elongation is shown in column 17. The area of the net section as shown in column 18 was the area of the section through the pin hole.

In the tests of two different alloys, carbon steel and aluminum alloy, Huggenberger Tensometers were used to obtain data to note the change in slope on the curves which might indicate the action of the material around the pin hole.

The results of this data are shown in the curves of Fig. 16 and 17 as load-strain curves. Separate curves are plottes for the readings taken from the tensometers mounted on the east and west sides of the specimen, and from the tensometers mounted on the top of the specimen behind the pin hole. Data for the steel alloys were taken for the carbon steel as it was assumed that the steel would act similarly in all cases. Permanent set readings were taken in these data at the same intervals as were taken for the pin plate data.

For the five-inch plates of carbon steel a change in slope occurs on the top tensometers before it does on the side tensometers. The change occurs at a load of 17,000 lb. on the side tensometers, while the change occurs at 15,000 lb. on the top tensometer. This denotes a yielding first occured at the top center of the plate.

In the case of the four-inch plate of carbon steel. a change of slope occurs first on the side of the plate. The change occurs at 13,000 lb. on the side tensometers, while the change occurs at 21,000 lb. on the top tensometer. This shows that yield first occurred on the sides of the plate.

The points of initial yield as shown on the Huggenberger curves, corresponds to the portion of ultimate failure as denoted by the design of the plates. That is, the plates designed to fail in tension had an initial yield at the sides of the pin hole, while the plates designed to fail in bearing had an initial yield at the top of the plate.

Another fact is that the signs of initial yielding in the carbon plates as shown by the Huggenberger curves is much lower than an initial yielding shown on the pin-connected plate load-strain curves of an average 19,000 lb. taken at the point where the curve deviates from the original elastic straight-line portion. Therefore a yielding was denoted by the Huggenberger tensometers before it was noted by the Ames dials. Therefore, we can see that a yielding was noted in the neighborhood of the edges of the plate before the yielding of the pin holes occurred.

In the data of Table 1 of columns 11 and 12 of surface slip lines a yielding as shown by the Huggenberger tensometers occurred much before a yielding was shown by the slip lines. This proves the statement made by Mr. Moore, which was quoted in the Test Program on page 8, is correct. An explanation of this would be that the initial slip denoted by the Huggenberger tensometers was so slight that there would not be enough strain in the mill scale to produce a tension failure in the scale. However, at the point where the slip was first noticed by the peeling off of the mill scale, whitewash being used to accentuate the mill scale peeling, the curves of the Huggenberger tensometers show a much more definite yielding than at the initial slip. This further proves the above statement made as an explanation.

In the curves for the Huggenberger tensometer data for the aluminum alloy, the initial yielding in the case of the five-inch plate was first noticed on the top tensometer, and the initial yielding for the four-inch plate was first noticed on the side tensometers. This agrees also with the specifications of design that the five-inch plate fail in bearing and the four-inch plate fail in tension. Since it was impossible to denote any slip lines due to the fact that there is no mill scale on aluminum alloy, there can be no comparison of the initial yielding as shown by the Huggenberger tensometers with that of the slip lines. With the Huggenberger data the yielding first occurred on the five-inch plate at a load of 24,000 lb., and on the four-inch plates at a load of 26,000 lb. The initial yielding as shown on the pin plate load-strain curves, taken at the point where the curve deviates from the original straight-line portion, is very much higher than the yielding shown on the Huggenberger curves.

The four-inch plates that were designed to fail in tension did so in every case, as can be seen in Fig. 18. The carbon steel proved the most ductile metal by elongating considerably in the pin hole. The low alloy steel and the silicon steel elongated somewhat but did not do so quite as much as did the carbon steel. The aluminum alloy proved the least ductile, as the elongation was small, and the specimen broke on both sides of the pin hole. The complete breaking of the specimen took place only in the aluminum alloy specimens. In the cases of the steel plates, the sides that remained in tact were reduced considerably in area by necking. The aluminum alloy specimens failed suddenly without much sign of necking, whereas the steel plates yielded considerably before failure. In fact, at the failure of the aluminum alloy specimens the top part of the specimen flew for considerable distance in an upward direction, and landed several feet from the testing machine.

The five-inch plates that were designed to fail by ? bearing, did so in every case with the exception of one aluminum alloy specimen, which can be seen in Fig. 19. The aluminum alloy specimen No. A7-1 failed at the sides in tension. The section that it failed in was not the most reduced section as there was considerable reduction of area on the top side of the pin hole. The failure surface in this case was very jagged, unlike the break in the other aluminum alloy specimen No. A7-2, which broke with a smooth fracture. As in the tests of the four-inch plates, the five-inch plates of carbon steel showed considerable ductility, by elongating at the pin hole quite a bit. The pin hole in the five-inch plate of carbon steel elongated more so than did the four-inch plate of the same metal. This is to be expected, however, as the most reduced section in this case is at the top of the pin hole. The specimens of silicon steel and low alloy steel elongated considerably, and the aluminum alloy specimens proved the least ductile.

In all cases, with the exception of the aluminum alloy specimen No. A7-1, there was considerable reduction of area at the top of the pin hole due to necking, and very little necking on the sides of the pin hole. In all cases, the top of the plate flared out when the plate began to yield considerably. This phenomenon did not occur in the four-inch plates, as they pulled in at the point of fracture. In three specimens, No. C7-2, M7-2, and C7-1, the point of failure was at the side of the reduced section, instead of being exactly at the midpoint, as was the case with the other specimens.

SUMMARY AND CONCLUSIONS

I. In a review of Table 1, the following conclusions can be drawn:

1. The metals in order of their ultimate strength are: Silicon Steel, Low Alloy Steel, Aluminum Alloy, and Carbon Steel. The position of the Carbon Steel in this order is due to the Soft poor carbon steel that was used. If standard strength carbon steel had been used, its value would be nearly the same as the aluminum alloy.
2. In yield strength the silicon steel, the low alloy steel, and the aluminum alloy have approximately the same value, with the aluminum alloy being the lowest by a very slight amount. The carbon steel value is very low, but even if standard strength material had been used, the value would not have been as high as the yield strength of the other materials.
3. The carbon steel proved the most ductile metal, and the aluminum alloy the least ductile. The other two metals, silicon steel and low alloy steel, were approximately the same, with the low alloy steel being more ductile than the silicon steel.

II. In a review of Table 2, for the tensile properties, the same ratings as are assigned above can be assigned again in comparison of the different metals.

III. The following conclusions are based on the ratios tabulated in Table 3.

1. In the plates of four-inch width, designed to fail in tension through the net section;

   a. The ratio of the arbitrary "general yield" of the plate specimens to their ultimate strength was more than the ratio between lower yield point (or 0.2 per cent offset in the case of aluminum) as obtained from the standard tensile test. The same plate ratios were slightly less than the corresponding tensile test ratios based on the upper yield point, with the exception of the silicon steel plate tests, S6-1 and S6-2 which gave erratic results.

   b. The ratio of ultimate plate strength to ultimate strength predicted by formula (1) is very nearly unity in all cases. Hence, the average nominal tensile stress through the net section of the specimens designed to fail in tension was very nearly the same as the nominal ultimate tensile stress of the tensile coupon tests.

2. In the plates of five-inch width, designed to fail in bearing behind the pin hole;

a. The ratio of the arbitrary "general yield" of the plate specimens to their ultimate strength was less than the ratio between the lower yield point (or 0.2 per cent offset in the case of aluminum) as obtained from the standard tensile test, except in the case of silicon steel, which was about equal. The same plate ratios were less in every case than the corresponding tensile test ratios based on the upper yield point. The values of this ratio are the same as the values for the four-inch plates.

b. The ratio of ultimate plate strength to ultimate strength predicted by formula (1) is close to unity, but is approximately two per cent less then unity in every case.

IV. The carbon steel plate did not agree with the standard specifications of yield strength or ultimate strength. This is due to the fact that a Softer poorer grade of carbon steel than the standard was used for the tests.

V. The use of whitewash to accentuate the mill scale peeling in order to investigate the initial yielding of the material is not reliable. The use of Huggenberger Tensometers will show on the resulting load-deformation curves a yielding at a lower load than will the slip lines in the mill scale. However, the mill scale peeling will give a picture of the direction and extent of principal overstraining of the material above the yield point.

ACKNOWLEDGMENT

The study of pin-connected plates was suggested and suppervised by Dr. Bruce G. Johnston, Associate Professor of Civil Engineering and Associate Director of Fritz Engineering Laboratory at Lehigh University, Bethlehem, Pennsylvania. The tests for this study were conducted in Fritz Engineering Laboratory. Special acknowledgment is due Dr. Johnston for his patience and advice which made this thesis possible. Acknowledgment is made to the staff of Fritz Engineering Laboratory for making the tensile coupon tests and for assisting in setting up the apparatus and the operation of some of the tests.

LIST OF TABLES

TABLE 1

DIMENSIONS AND TEST DATA ~ PIN CONNECTED PLATES

Specimen Number	Nominal Dimensions in inches		Measured Dimensions in inches					Dimension Ratios			Surface Slip Lines Load in Kips		Load in Kips			Vertical Diameter of Hole After Test inches	Elongation inches	Area of Net Section sq. in.
	D	W	t	D	$S_{(average)}$	W	e	S/D	e/D	W/D	First Observed	General Spread	$A \times S_{bt}$	Yield Strength	Ultimate Strength			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
S6-1	2.00	4.00	0.498	2.002	1.007	4.00	1.508	.503	.753	2.00	47.0	53-64	91.6	52.5	84.2	2.77	0.77	0.995
S6-2	2.00	4.00	0.505	2.002	1.006	3.98	1.504	.503	.751	1.99			91.6	58.5	91.5	2.77	0.77	0.999
S7-1	2.00	5.00	0.498	2.004	1.507	4.98	1.026	.752	.512	2.49	36.0	41-45	88.6	46.7	82.8	2.98	0.98	1.482
S7-2	2.00	5.00	0.496	2.003	1.506	4.99	1.026	.752	.512	2.49			88.6	47.2	82.6	2.96	0.96	1.482
C6-1	2.00	4.00	0.507	2.004	1.009	4.00	1.507	.503	.752	2.00	19.0	26-30	47.05	27.7	46.1	3.08	1.08	1.012
C6-2	2.00	4.00	0.508	2.005	1.004	3.99	1.504	.501	.750	1.99			46.9	27.5	46.8	3.03	1.03	1.008
C7-1	2.00	5.00	0.501	2.004	1.508	5.00	1.031	.752	.514	2.50	18.0	21	45.6	22.5	46.25	3.83	1.83	1.501
C7-2	2.00	5.00	0.503	2.005	1.506	5.00	1.032	.751	.515	2.49			45.7	24.5	46.8	3.96	1.96	1.506
M6-1	2.00	4.00	0.502	2.003	1.006	4.00	1.514	.502	.756	2.00	36.0	54-60	77.5	55.5	77.9	2.83	0.83	1.002
M6-2	2.00	4.00	0.508	2.003	1.008	4.00	1.523	.503	.760	2.00	38.0	56-62	77.7	55.7	77.9	2.88	0.88	1.014
M7-1	2.00	5.00	0.508	2.004	1.506	4.98	1.023	.751	.510	2.49	40.0	52	75.0	47.2	74.45	3.26	1.26	1.519
M7-2	2.00	5.00	0.507	2.007	1.505	4.98	1.032	.750	.514	2.48	29.0	44-50	75.3	49.2	83.0	3.27	1.27	1.507
A6-1	2.00	4.00	0.504	2.000	1.013	4.00	1.512	.507	.756	2.00	—	—	62.8	54.0	64.2	2.19	0.19	1.008
A6-2	2.00	4.00	0.503	2.000	1.013	4.00	1.505	.507	.753	2.00	—	—	62.8	54.0	63.75	2.17	0.17	1.006
A7-1	2.00	5.00	0.503	2.000	1.505	4.99	1.012	.753	.506	2.50	—	—	59.8	47.5	63.3	2.62	0.62	1.504
A7-2	2.00	5.00	0.504	2.000	1.515	4.98	1.013	.758	.507	2.49	—	—	60.0	46.0	59.6	2.35	0.35	1.502

TABLE 2

PHYSICAL PROPERTIES OF MATERIALS BASED ON TENSILE COUPON TESTS

Material	Specimen Number	Source	TENSILE STRESS, Kips/Sq. in.						Ratio σ_{UY} to σ_{LY}	Ratio σ_{UY} to σ_{NM}	Elongation in 2 inches percent	Reduction of Area percent	Ductility Indices		
			σ_P	σ_{UY}	σ_{LY}	σ_{NM}	σ_{TM}	σ_{TB}					ε_u	ε_n	ε_b
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Low Alloy Steel	M-1	½" Pl.	50.0	55.5	52.0	77.2	90.6	148.7	1.07	0.72	31.5	67.1	.1613	1.0508	1.2121
	M-2	½" Pl.	45.0	55.5	51.0	77.3	89.7	146.0	1.09	0.77	33.0	65.5	.1613	1.1663	1.3276
Silicon Steel	S-1	½" Pl.	40.0	55.0	51.5	91.3	99.4	149.7	1.07	0.60	24.5	52.9	.086	.8198	.9058
	S-2	½" Pl.	40.0	51.0	49.0	90.8	106.5	157.7	1.04	0.56	21.0	55.9	.159	.7320	.8910
Carbon Steel	C-1	½" Pl.	22.8	28.8	27.8	46.7	60.4	100.2	1.04	0.62	40.5	76.5	.1660	1.285	1.451
	C-2	½" Pl.	21.0	28.0	27.4	46.8	58.5	106.0	1.02	0.60	44.0	76.7	.2231	1.241	1.464
Aluminum Alloy	Al-1	½" Pl.	21.8	—	48.0	62.6	70.7	74.3	—	—	13.0	25.0	.086	.1910	.2770
	Al-2	½" Pl.	33.0	—	48.7	61.2	66.6	74.3	—	—	14.0	24.4	.122	.1655	.2875

TABLE 3

RATIOS BASED ON YIELD AND ULTIMATE STRENGTHS

* Aluminum Alloy yield is at 0.2% offset

Specimen Number	PLATES Bearing Stress At General Yield	PLATES Bearing Stress At Ultimate Strength	Bearing Stress at Ultimate Strength predicted by formula	Yield Ratios Tensile Coupon Upper Yield / Ultimate	Yield Ratios Tensile Coupon Lower Yield / Ultimate	Yield Ratios Plate Specimens General Yield / Ultimate	Ratio, Ultimate Strength of plate to Ultimate Strength predicted by formula based on tensile ultimate strength
	1	2	3	4	5	6	7
S6-1	52.5	84.2	91.6			0.623	1.005
S6-2	58.5	91.5	91.6			0.640	1.005
Average				0.580	0.553	0.632	1.005
S7-1	46.7	82.8	88.6			0.565	0.973
S7-2	47.2	82.6	88.6			0.572	0.973
Average				0.580	0.553	0.569	0.973
C6-1	27.7	46.1	47.05			0.601	1.006
C6-2	27.5	46.8	46.9			0.588	1.002
Average				0.610	0.590	0.595	1.004
C7-1	22.5	46.25	45.6			0.487	0.976
C7-2	24.5	46.8	45.7			0.524	0.979
Average				0.610	0.590	0.506	0.978
M6-1	55.5	77.9	77.5			0.713	1.003
M6-2	55.7	77.9	77.7			0.716	1.005
Average				0.745	0.667	0.715	1.004
M7-1	47.2	74.45	75.0			0.636	0.971
M7-2	49.2	83.0	75.3			0.593	0.975
Average				0.745	0.667	0.615	0.973
A6-1	54.0	64.2	62.8			0.841	1.013
A6-2	54.0	63.75	62.8			0.848	1.013
Average				—	0.781 *	0.845	1.013
A7-1	47.5	63.3	59.8			0.750	0.967
A7-2	46.0	59.6	60.0			0.771	0.969
Average				—	0.781 *	0.761	0.968

LIST OF FIGURES

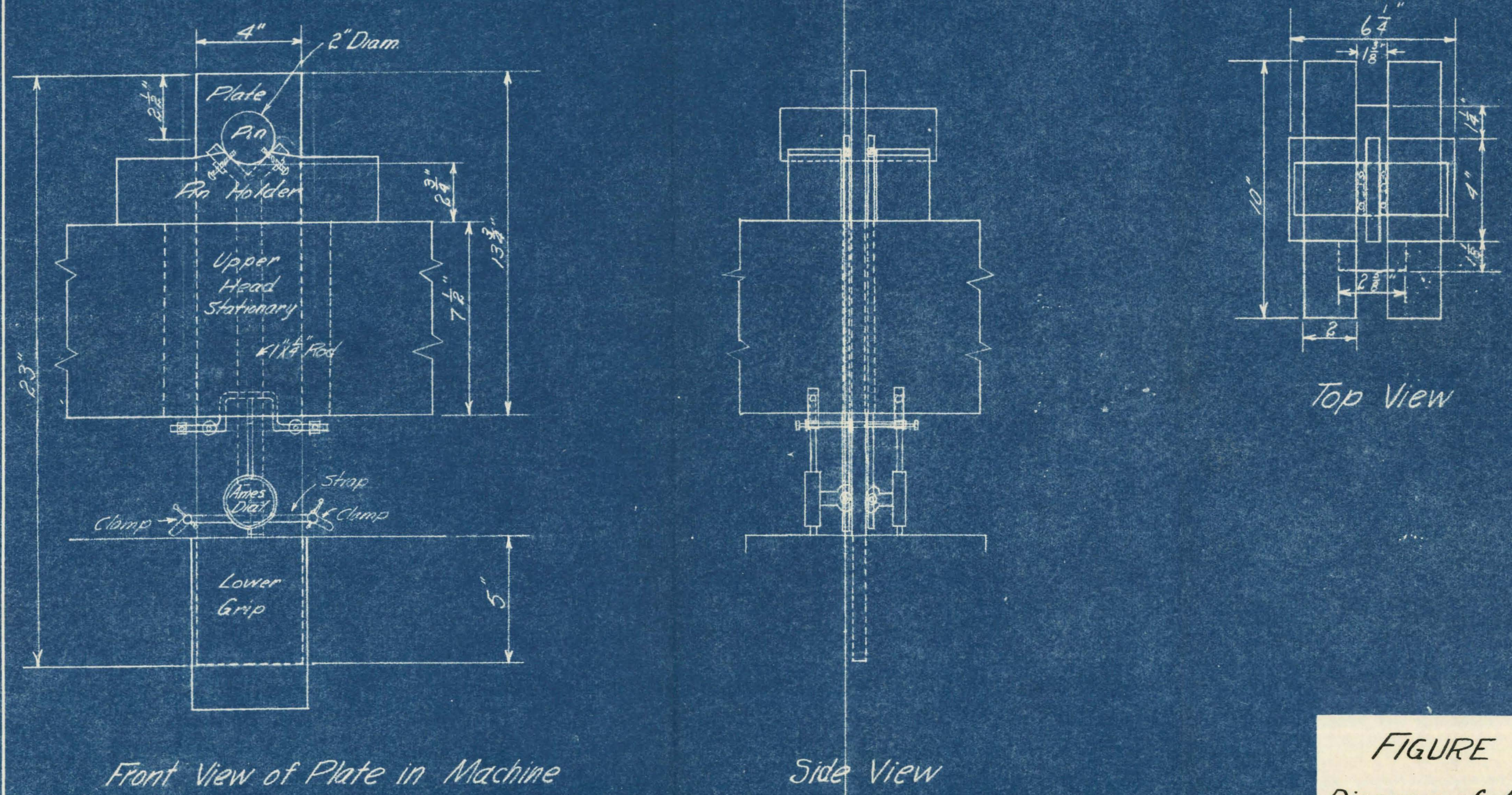

FIGURE 1
Diagram of Apparatus and Set Up

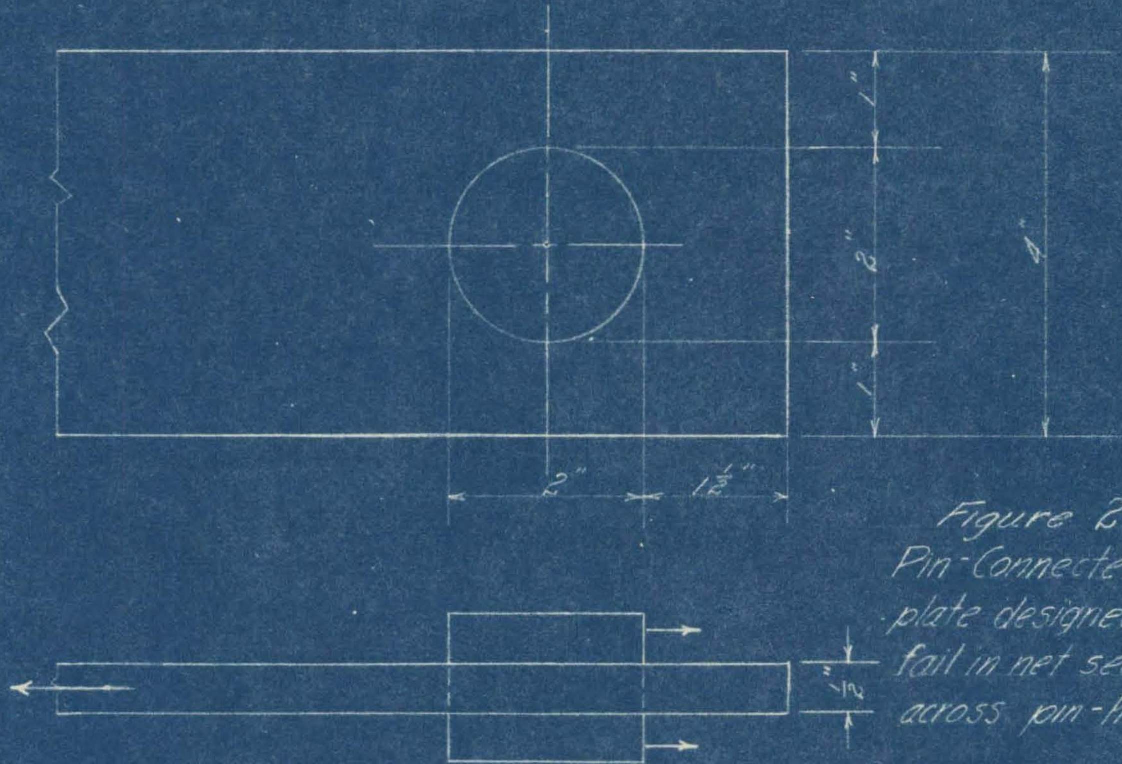

Figure 2
Pin-Connected plate designed to fail in net section across pin-hole

Overall Length = 23"

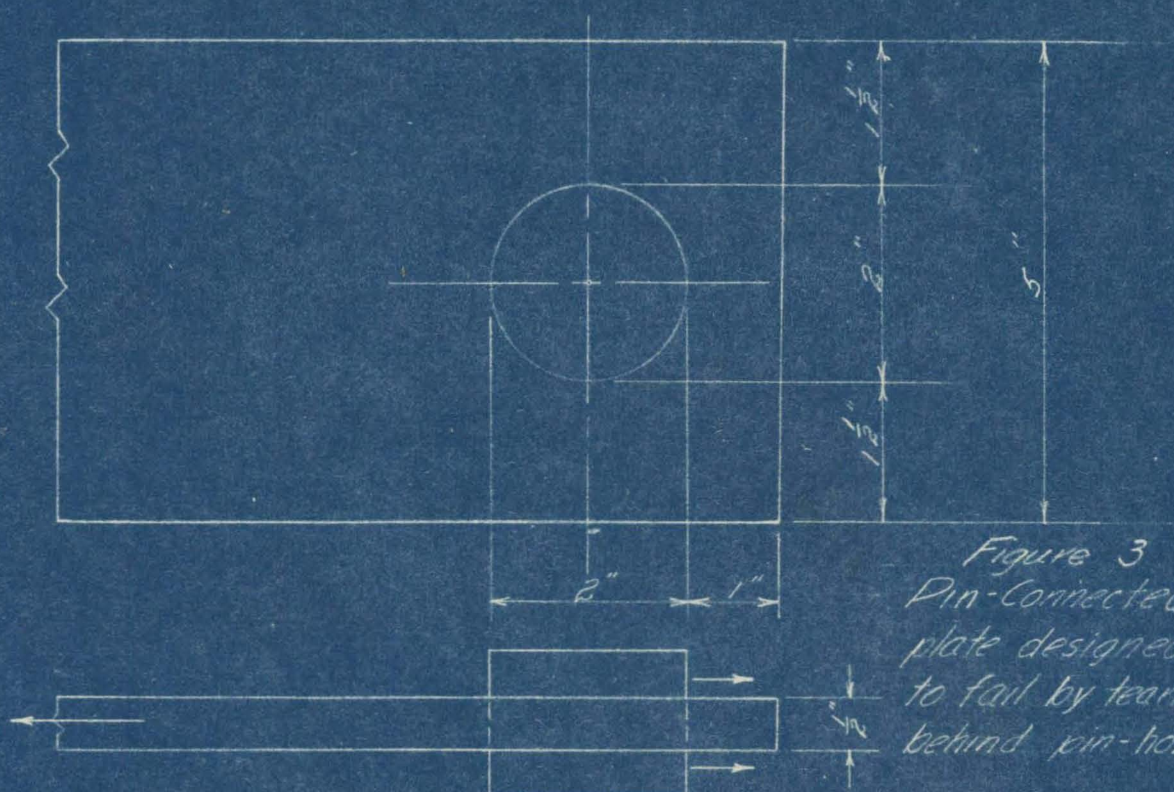

Figure 3
Pin-Connected plate designed to fail by tearing behind pin-hole

Overall Length = 23"

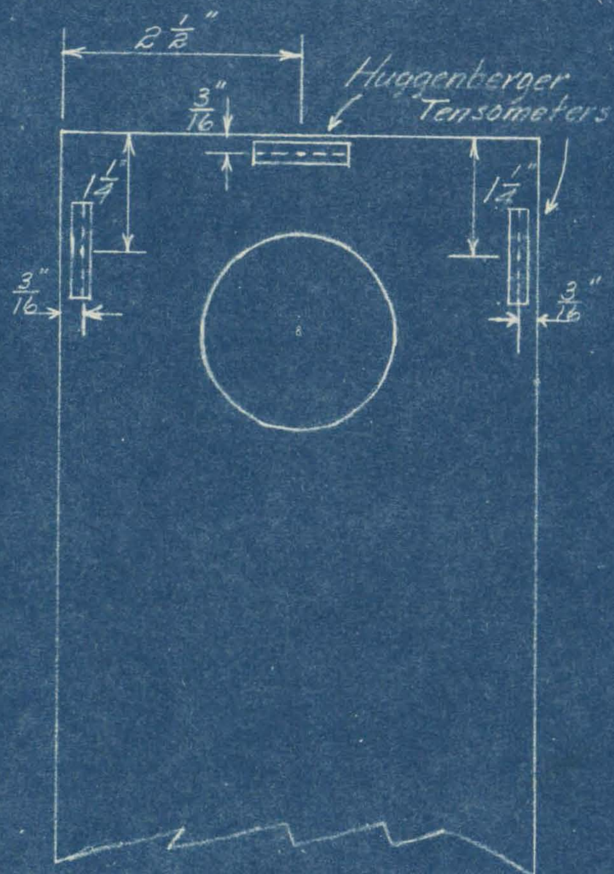

Figure 4

Position of Huggenberger Tensometers on a 5" Specimen

Position is same for 4" Specimens

Scale $\frac{1}{2}'' = 1''$

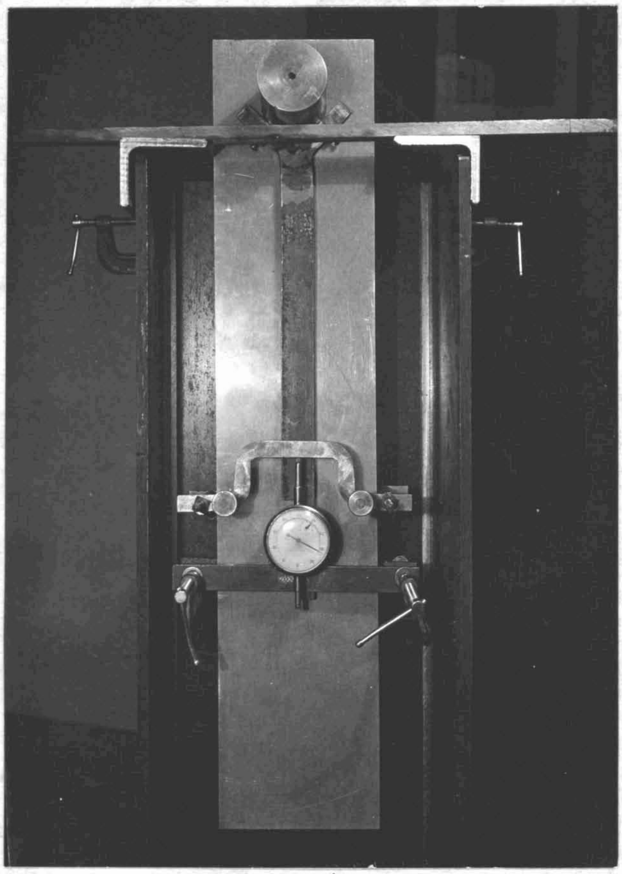

Fig. 5
Photograph of Apparatus Set-up

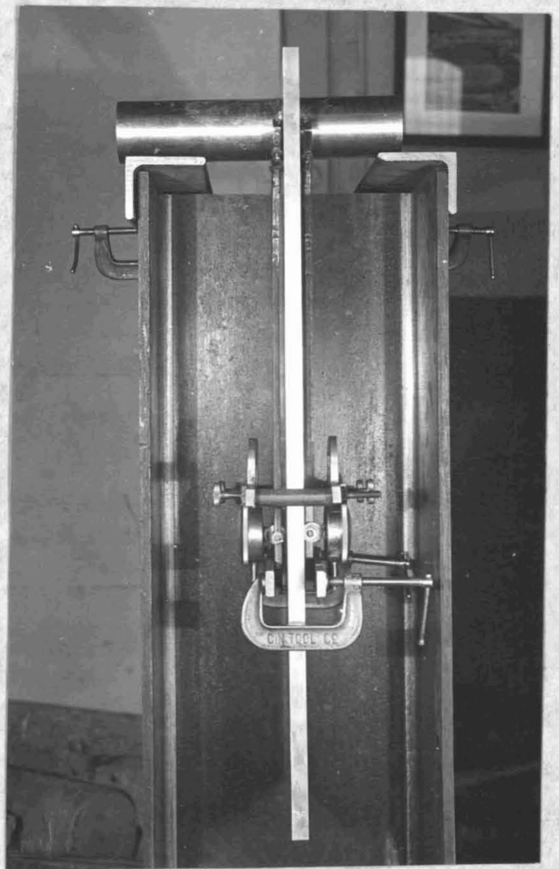

Fig. 6

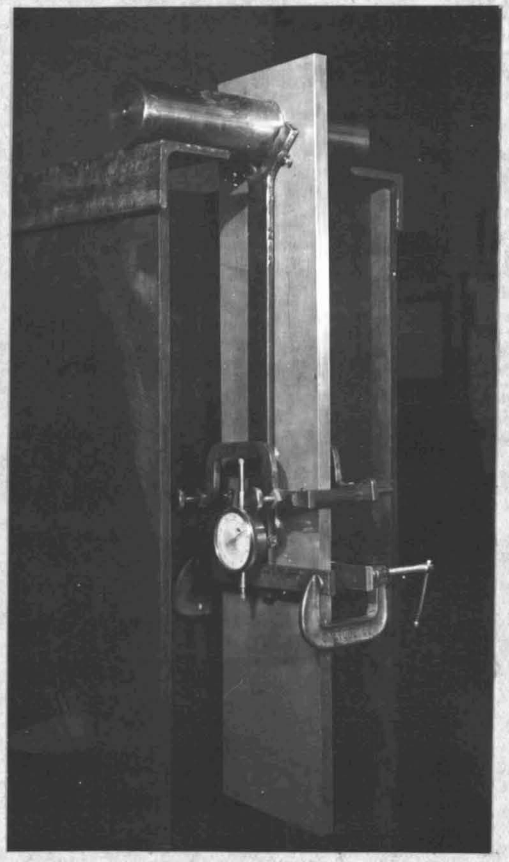

Fig. 7

Photographs of Apparatus Set-Up

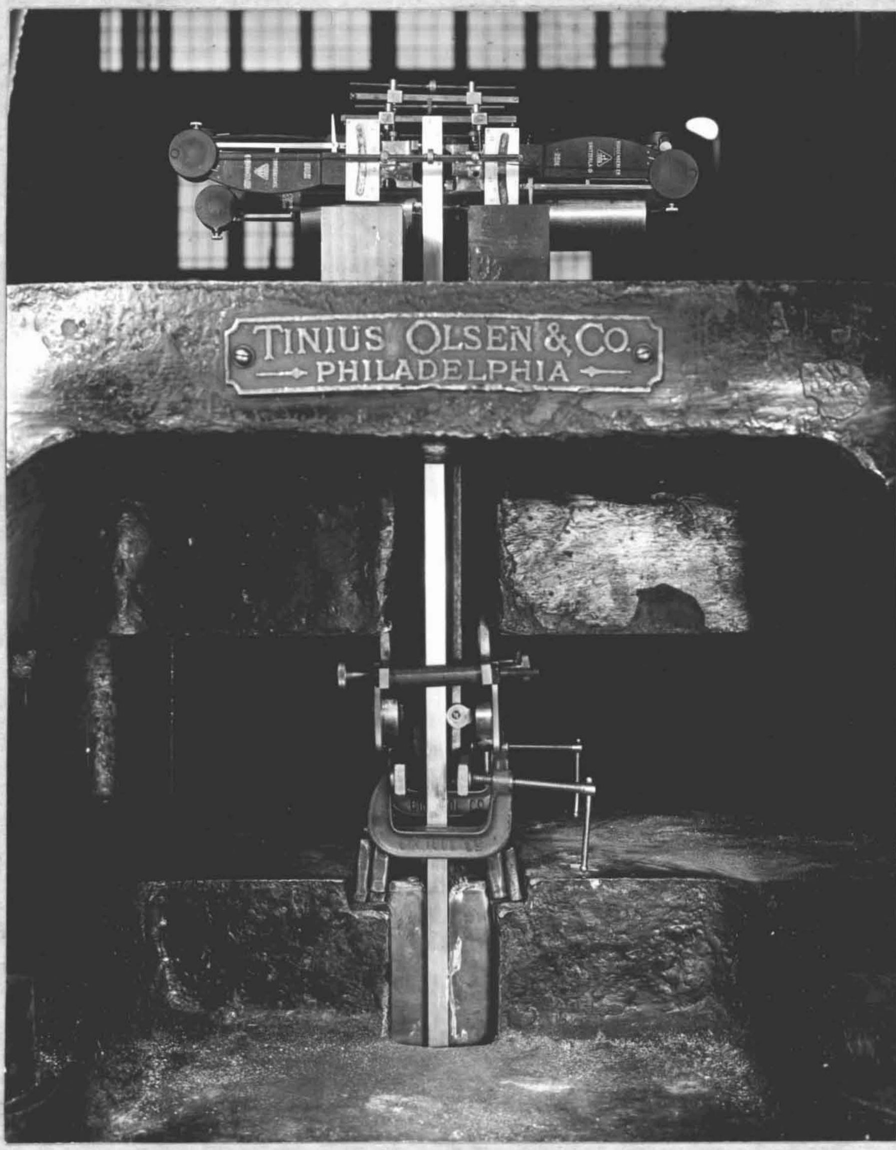

Fig. 8
Photograph of Apparatus Set-Up In The Testing Machine

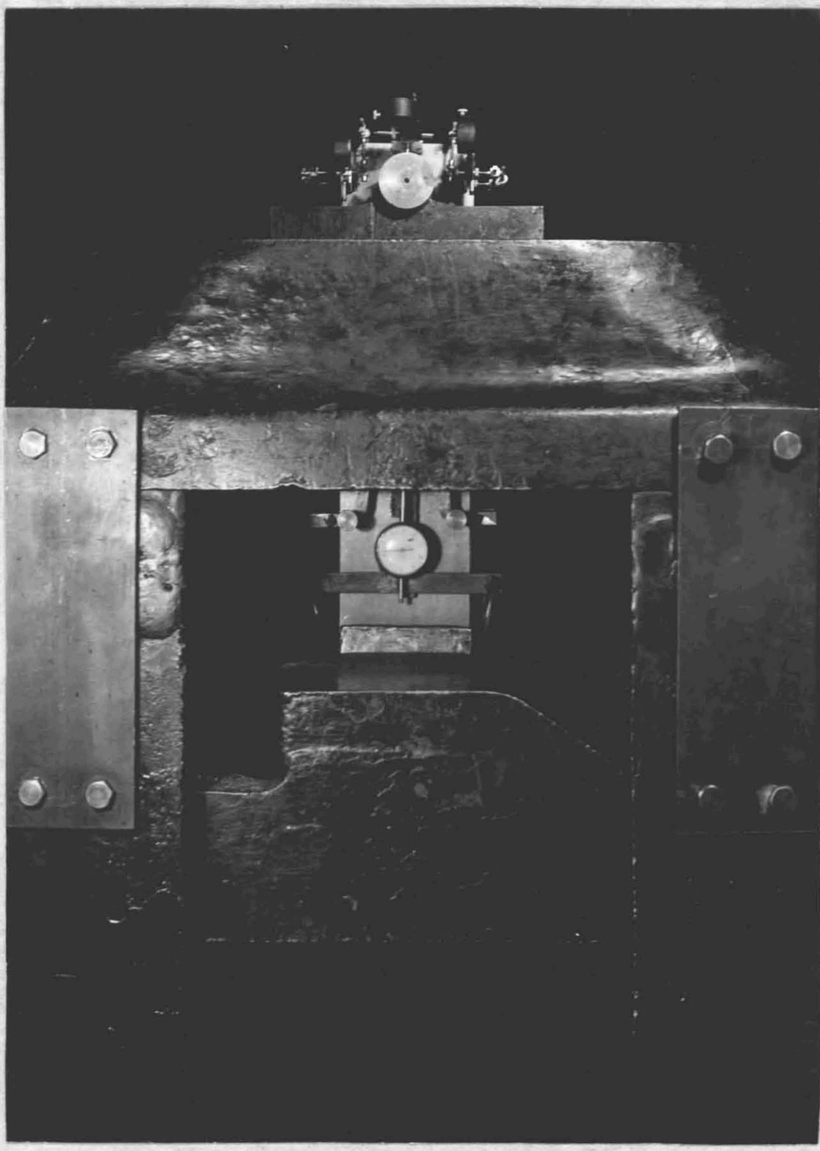

Fig. 9
Photograph of Apparatus Set-Up In The Testing Machine

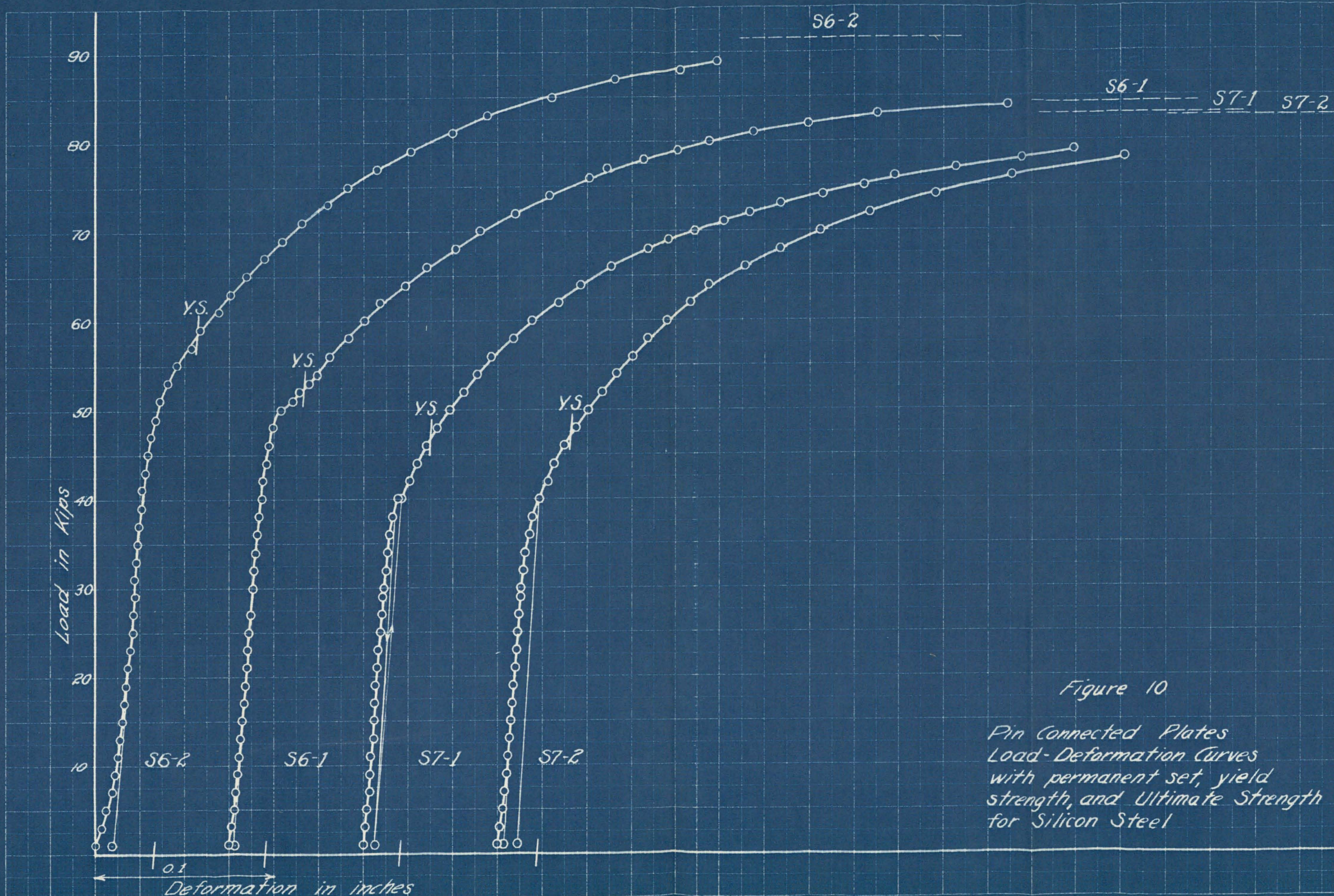

Figure 10

Pin Connected Plates
Load-Deformation Curves
with permanent set, yield
strength, and Ultimate Strength
for Silicon Steel

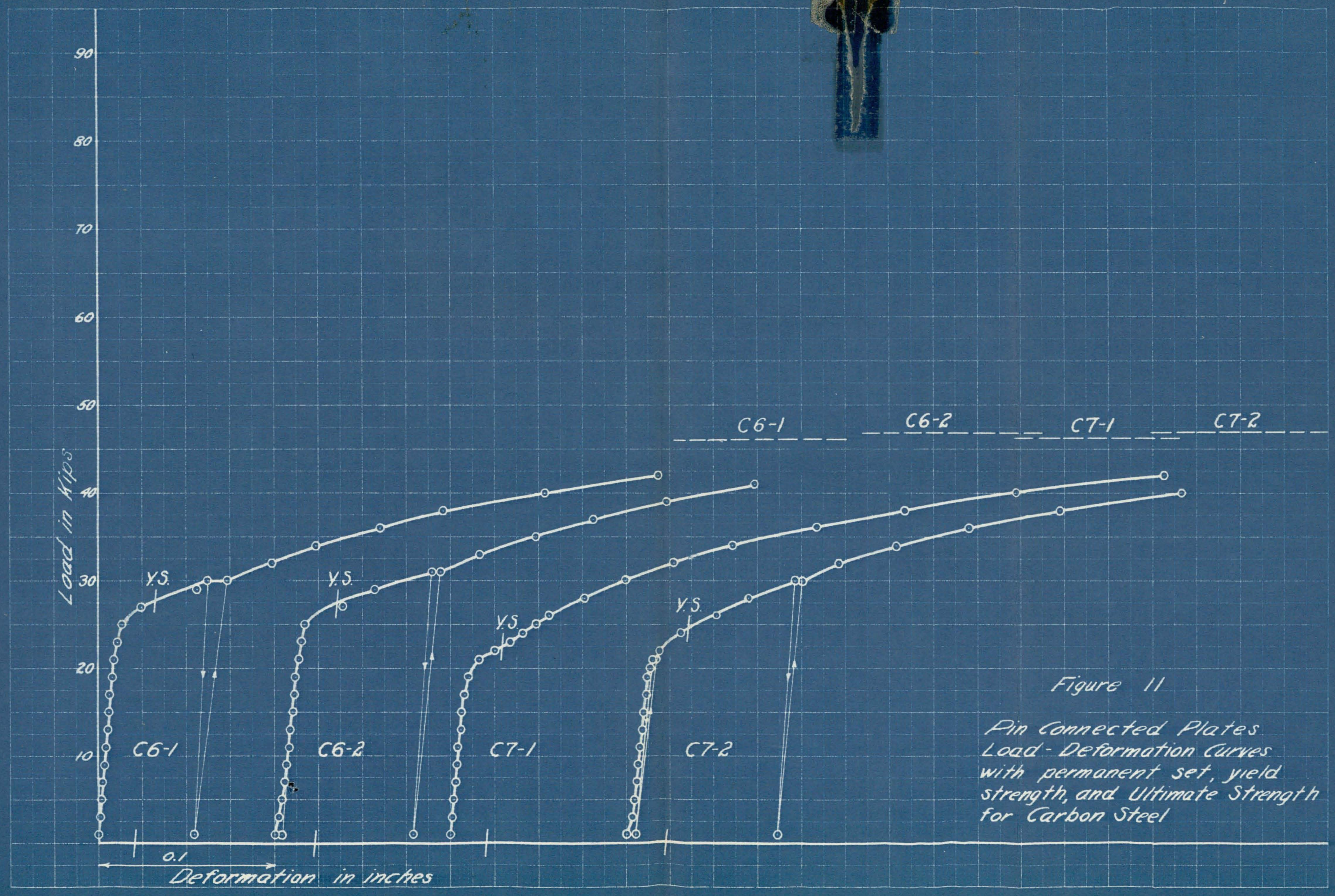

Figure 11

Pin Connected Plates
Load-Deformation Curves
with permanent set, yield
strength, and Ultimate Strength
for Carbon Steel

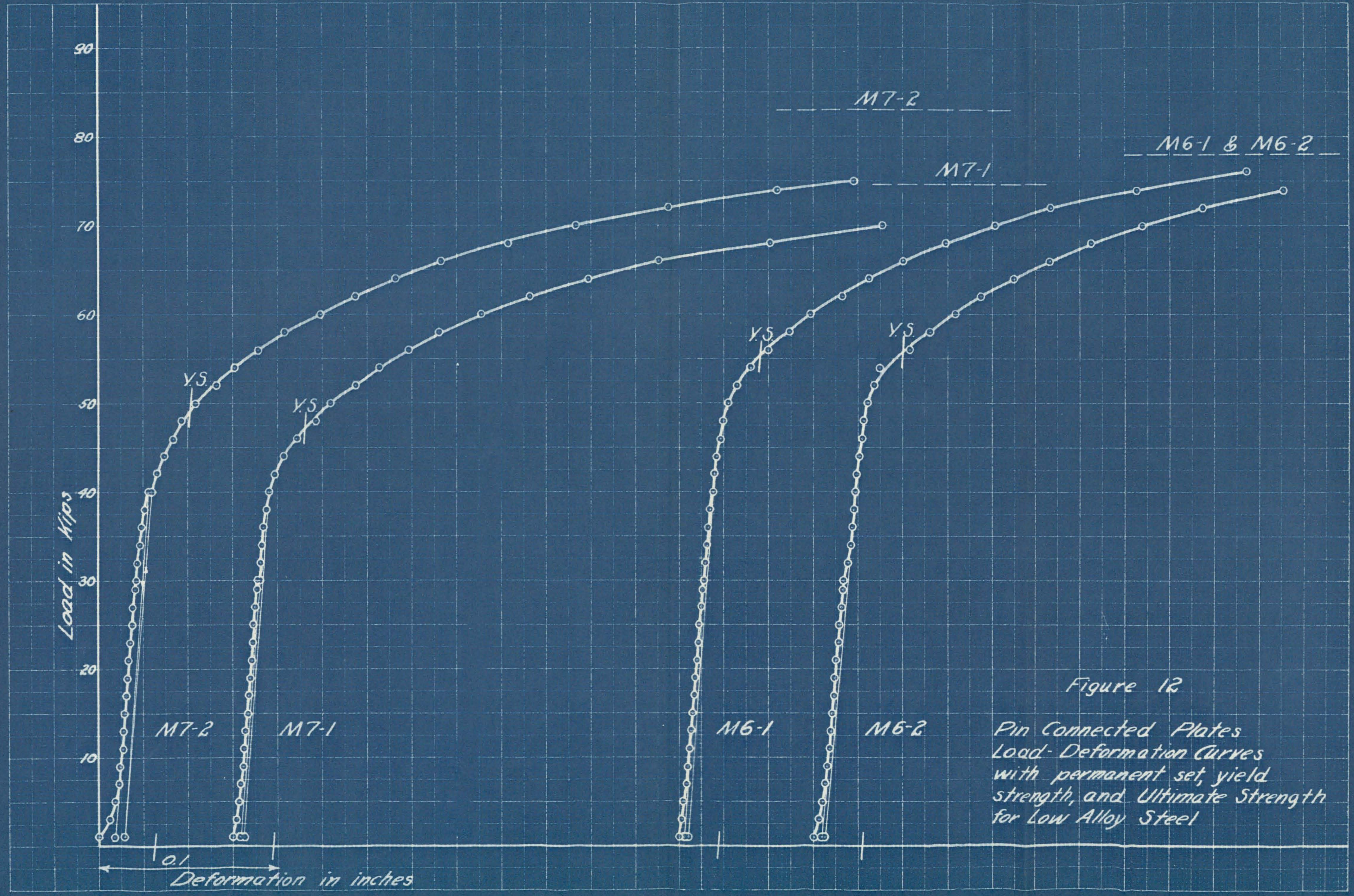

Figure 12

Pin Connected Plates
Load-Deformation Curves
with permanent set, yield
strength, and Ultimate Strength
for Low Alloy Steel

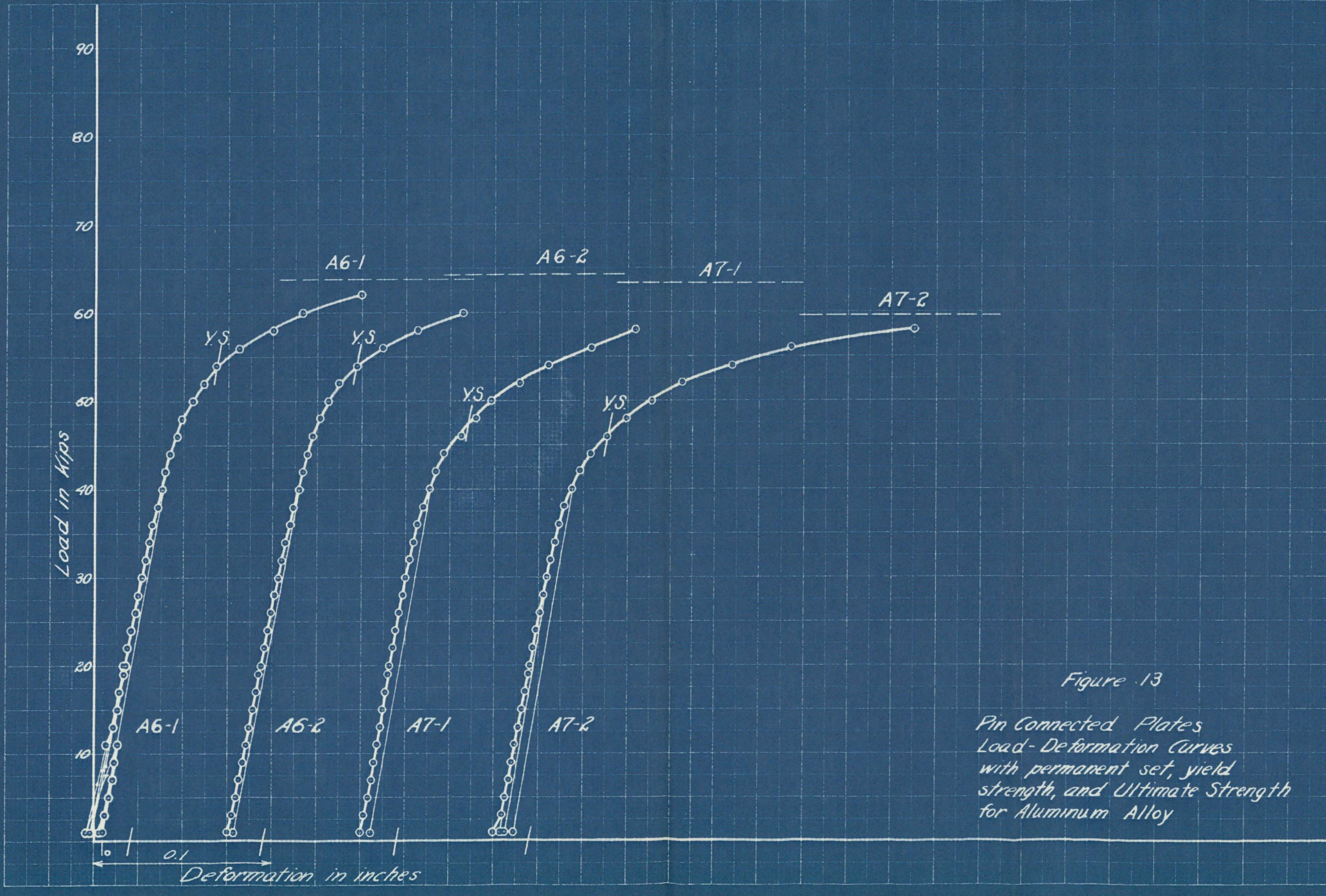

Figure 13

Pin Connected Plates
Load-Deformation Curves
with permanent set, yield
strength, and Ultimate Strength
for Aluminum Alloy

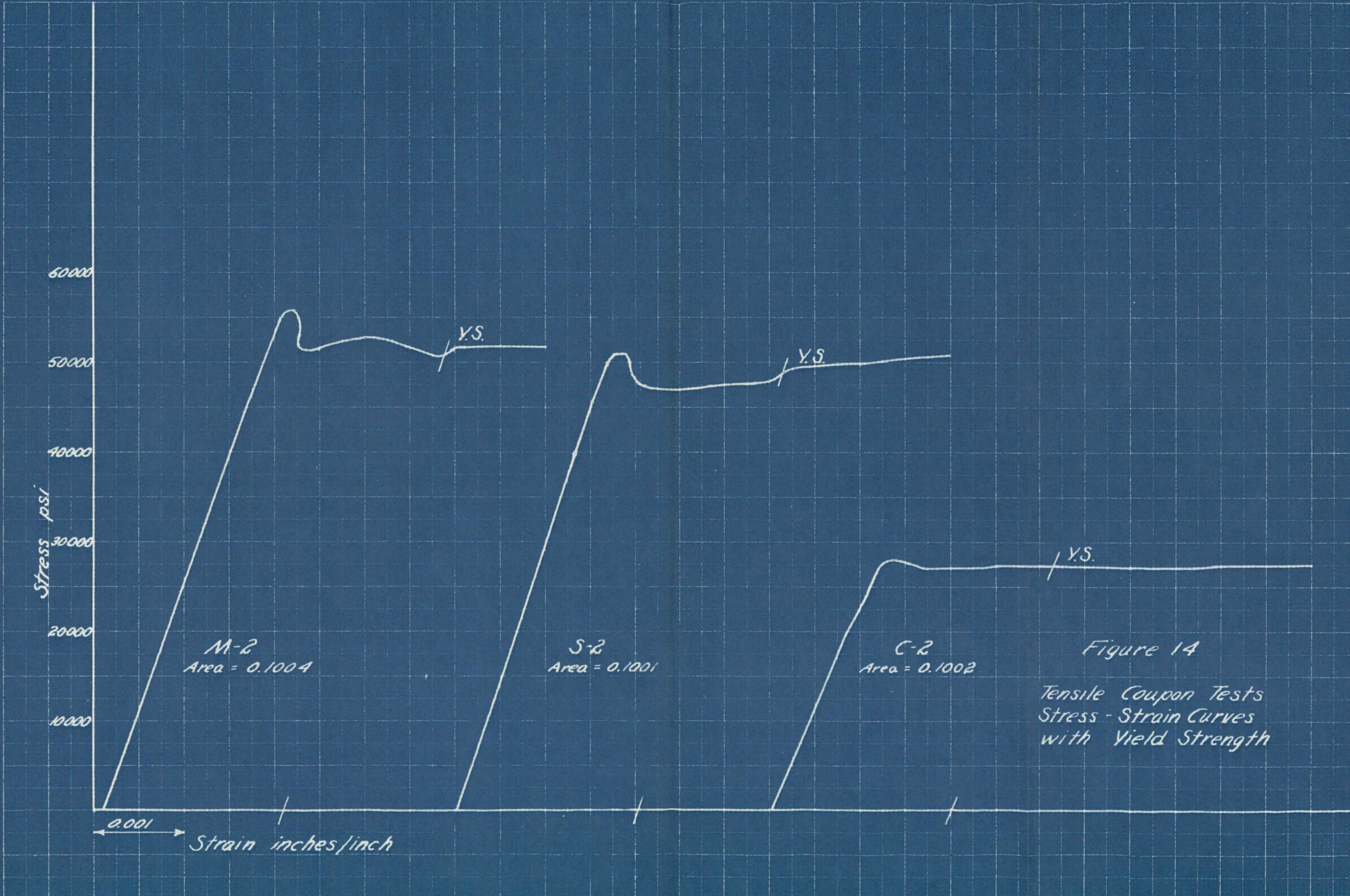

Figure 14

Tensile Coupon Tests
Stress - Strain Curves
with Yield Strength

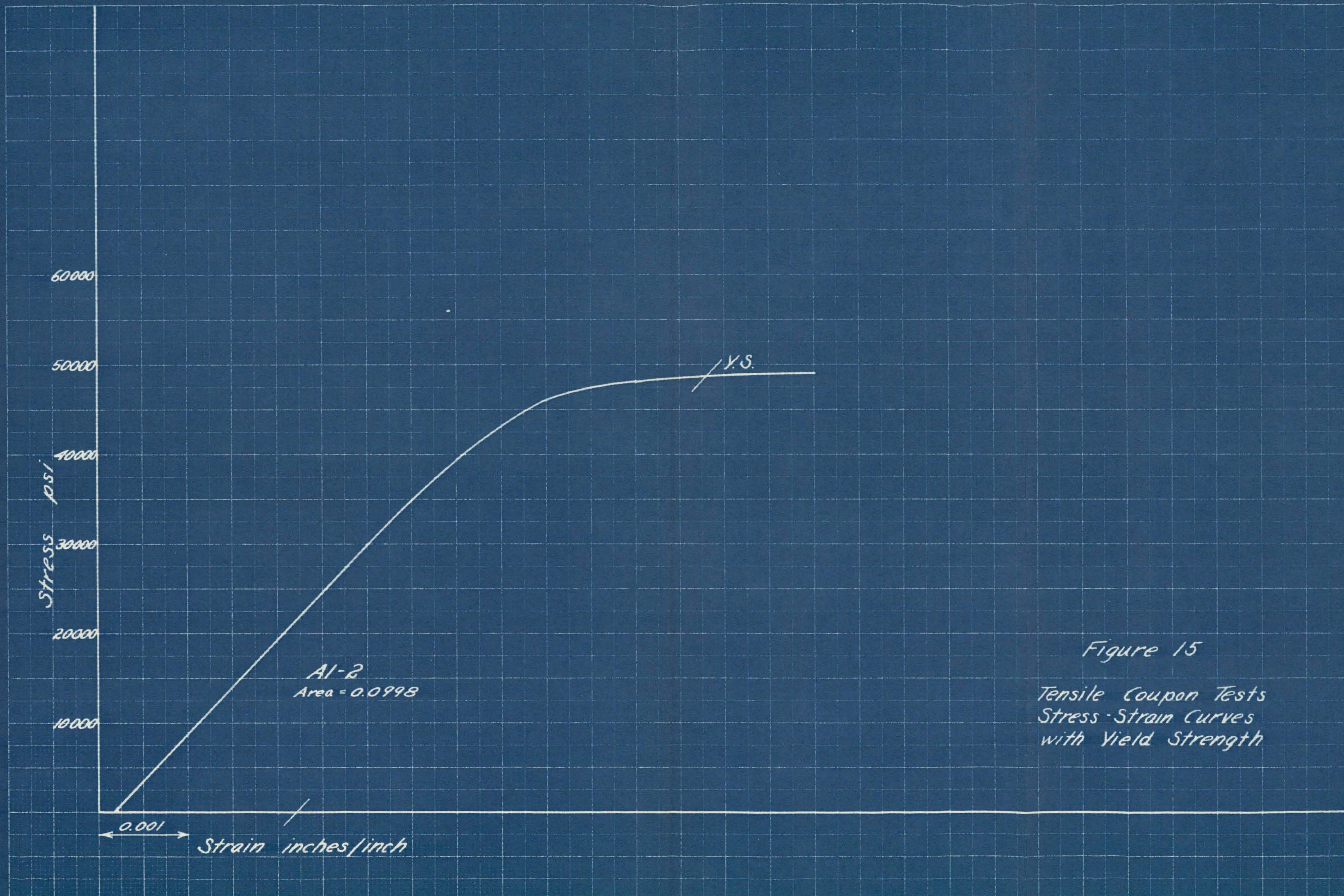

Figure 15

Tensile Coupon Tests
Stress-Strain Curves
with Yield Strength

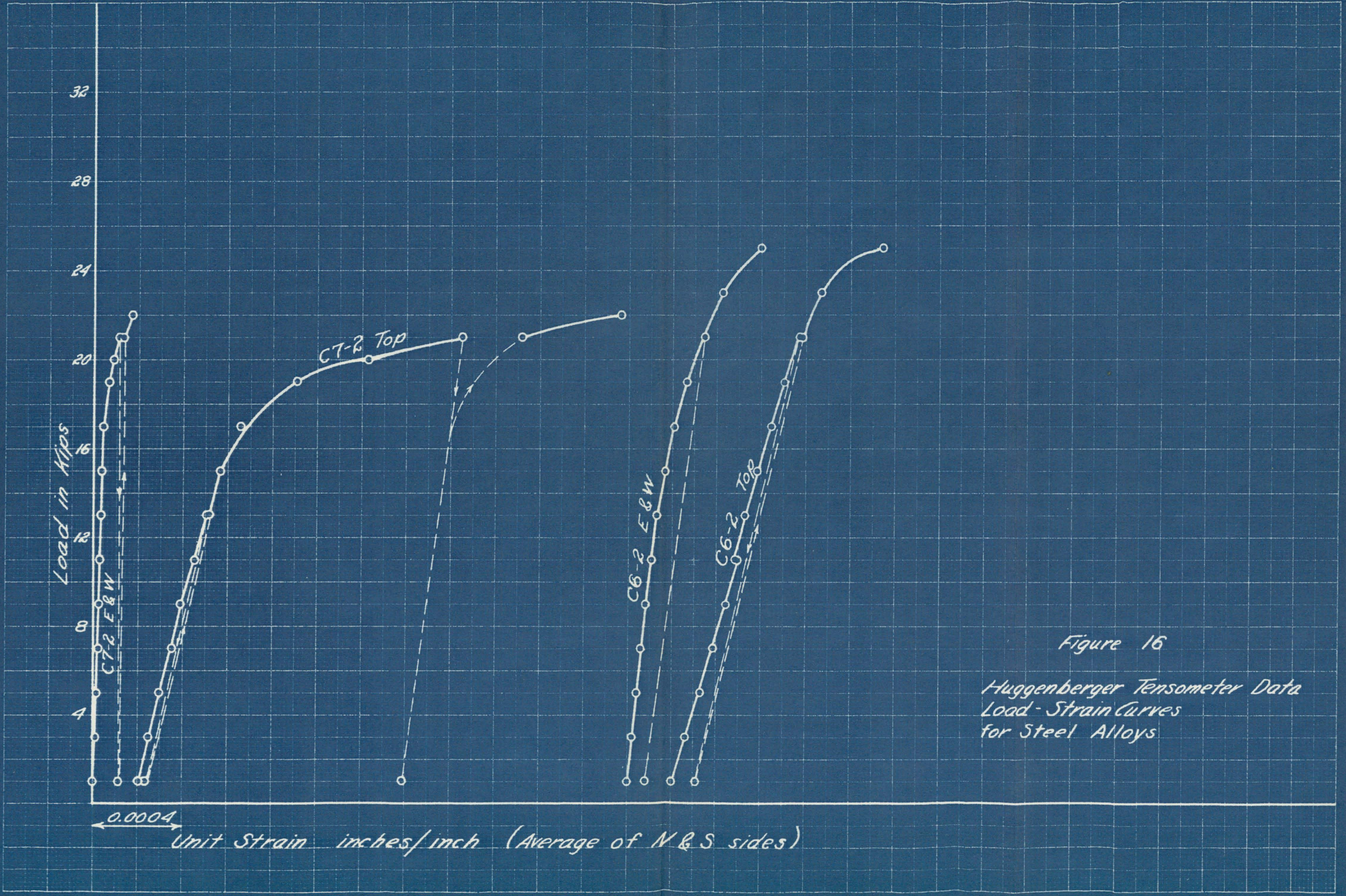

Figure 16

Huggenberger Tensometer Data
Load-Strain Curves
for Steel Alloys

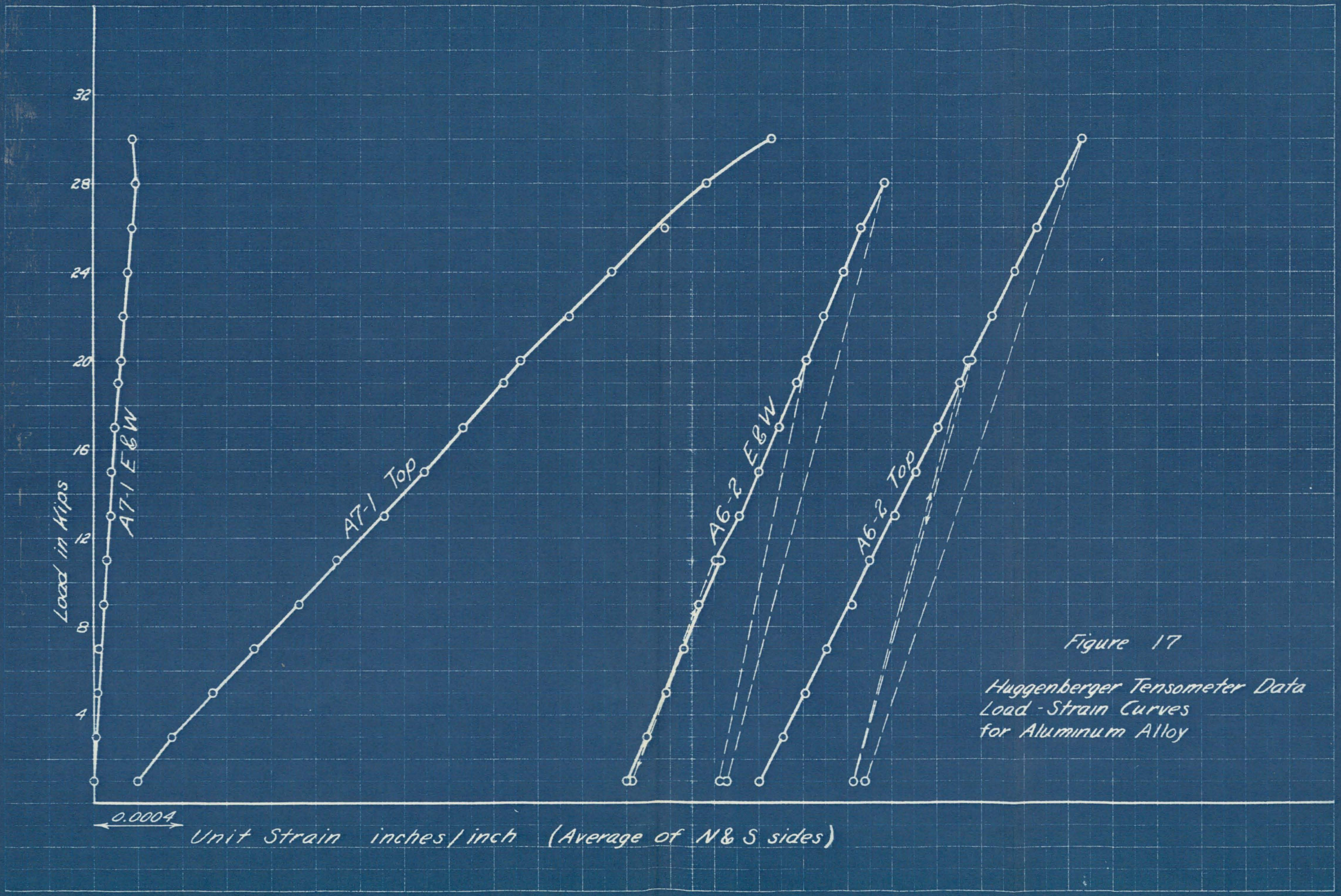

Figure 17

Huggenberger Tensometer Data
Load - Strain Curves
for Aluminum Alloy

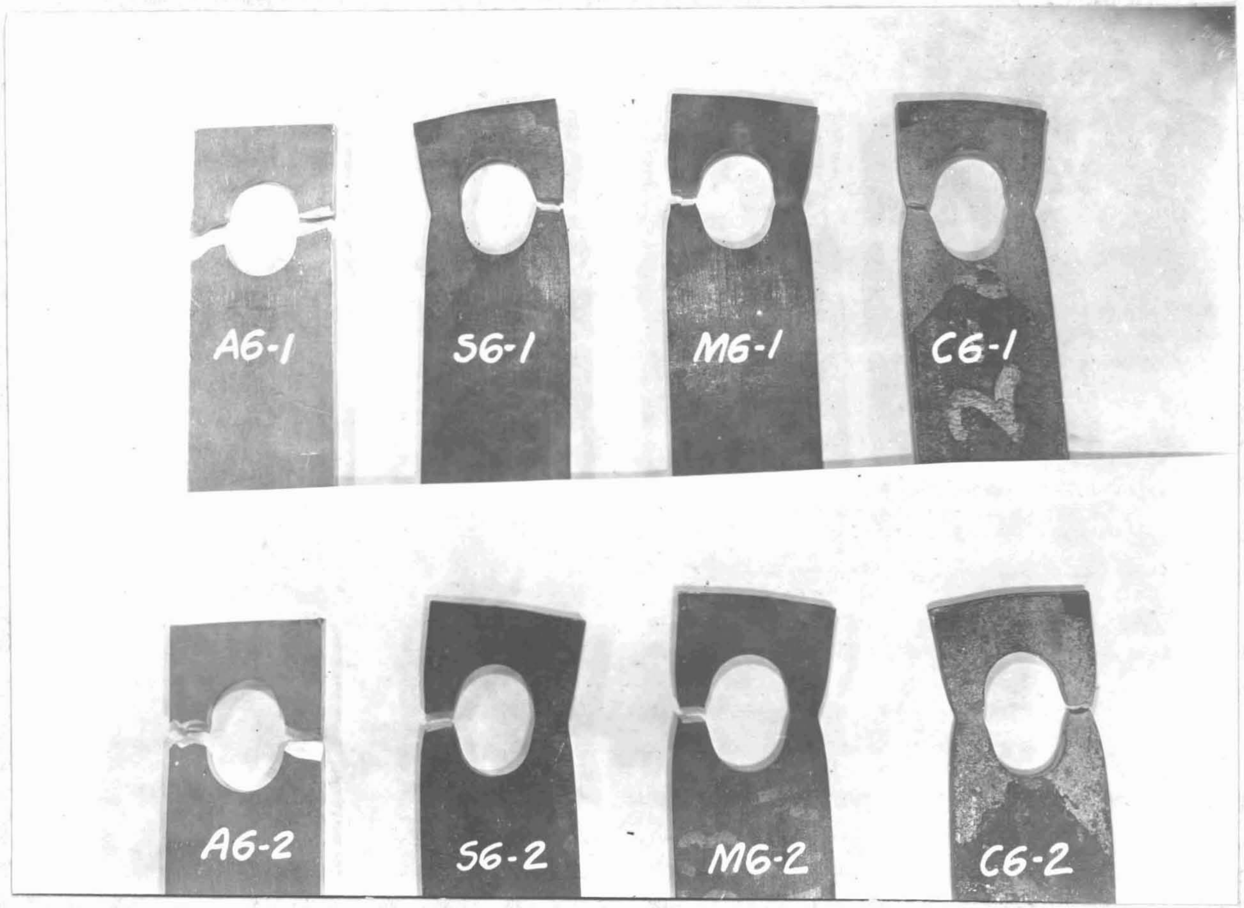

Fig. 18
Photograph of Specimen Failures for Four-Inch Plates

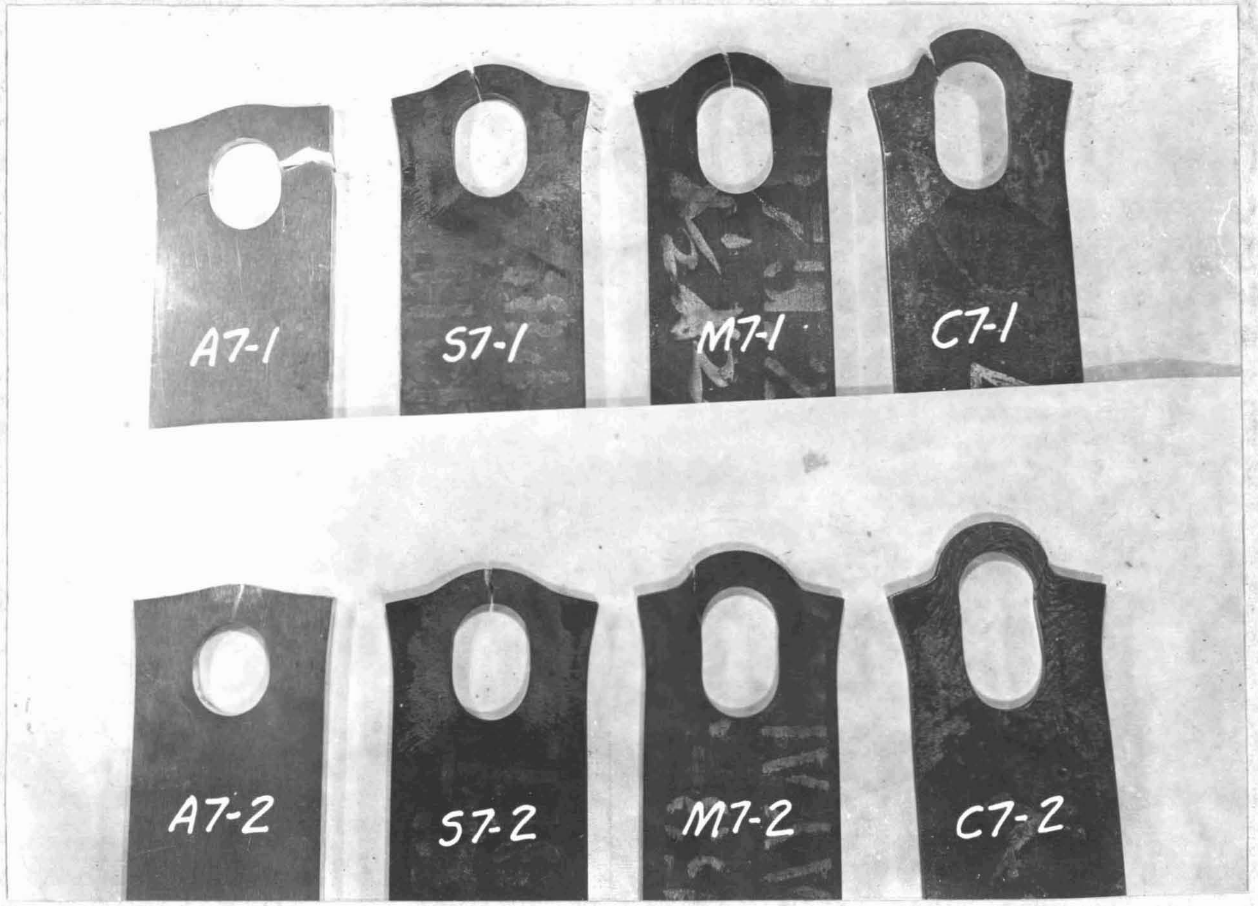

Fig. 19
Photograph of Specimen Failures for Five-Inch Plates